MODERN ELECTRO-DEPOSITION OF METALS.

Paper presented to the Institution, Birmingham Section, by S. Cowper-Coles.

ELECTRO-DEPOSITION is chiefly used for refining metals such as copper, zinc, lead, gold, nickel, and for coating iron and steel with other metals for protective and decorative purposes and for the direct production of finished articles such as sheets, tubes, wire direct from crude metal, or the ore, the production of bimetallic sheets and tubes, the building up of worn parts of machinery, and the production of parabolic reflectors for search lights and other purposes.

Some of the chief advances that made the electro-deposition of metals more practical and commercial in late years have been due to: (1) Improvements in electrical machinery, dynamos, etc.; (2) improvements in mechanical machinery, such as filtering apparatus; (3) improvements in agitating mechanisms, enabling a higher current density to be employed, and a more uniform deposit obtained; (4) appreciation of the fact that rapid circulation of the cathode or the electrolyte on the face of the cathode is essential when smooth deposits are to be obtained at high current densities; (5) a more accurate measurement of the acidity or alkalinity of solutions, by means of the pH or hydrogen ion control. One of the chief difficulties met with in electro-deposition has been the formation of growths and nodules on the surface or, more usually, the edges of deposits. These are caused by various reasons one of the chief being incorrect amount of acid. In a copper sulphate solution, for instance, when the acid is very low there is a fern like growth of trees; as the percentage of acid increases the growths get more and more solid until they are nodules. Where there is a correct acidity but the speed of rotation, or current density is not correct. These are frequent causes of extraneous growths. Nodules are often caused by a speck of dirt or an adherent gas bubble, and if the nodule is pulled out a speck of dirt can be seen at the base. Another difficulty is the formation of stream lines caused by incorrect density of solution. Such stream lines are a source of weakness and render the sheet useless commercially.

The formation of trees and nodules on the edges of deposits was for a long time the bugbear of electro-depositors, as the percentage of waste caused by such growths made the electro-deposition of

21st September, 1932. (Vol. XII, No. 3, March, 1933).

sheets useless commercially, but modern methods of correct control of acidity, rapidly rotating cathodes, and the use of specially designed baffles have unabled these difficulties to be surmounted. Sheets with perfectly smooth surface and mirror-like finish on one side, and clean straight edges, can now be produced continuously at a high current density—200-500 amperes or more per square foot of cathode surface. Speed has a marked effect on the nature of deposits.

Copper.

The production of pure metallic copper from its ores is not in any sense a simple matter : it involves a long and intricate series of operations. Briefly, the crude copper ore is crushed, concentrated, and, where necessary roasted. It is then smelted either in a blast furnace or in a reverbertory furnace. The resultant product is copper matt which usually consists of a mixture of copper and iron sulphides, and contains from 35 per cent. to 50 per cent. of copper This material is then Bessemerised in a convertor, similar in construction and principle to that employed in the Bessemer steel process. The crude copper produced is termed " blister copper," and this is further refined in a reverbertory and cast into flat anode plates, of suitable size and shape, from which pure cathode copper is produced by electrolysis. Finally, the cathode plates are remelted in a reverbertory furnace, and cast into ingots, slabs and wire bars. The production of high grade sheets, tubes and wire from this finally purified material involves a considerable number of rolling or drawing operations combined with annealing and pickling, all of which occupies much time. The electrolytic refining takes about a month, and the whole operations six or seven weeks. The process of the future will no doubt be electrolytic. Copper will be deposited from partially refined copper, or the ore, in one operation, producing finished tubes, sheets and wire, and other articles with equal, if not superior, physical and electrical properties to that obtained by the present methods of heat and mechanical treatment. It has now been proved beyond doubt that such material is of the highest quality, and the copper denser than copper produced by the ordinary methods, not porous.

The specimens exhibited to-night have been made in an apparatus which comprises a rectangular lead lined tank containing an aqueous solution of copper sulphate acidulated with sulphuric acid. The rotating cathode is built up of welded steel sheets, subsequently ground true, and upon its surface is deposited a preliminary coating of adhesive copper, which is treated with a special solution to prevent adhesion of the subsequent deposit. The drum is rotated by means of a belt from shafting driven by an electric motor. Plain brass bearings are employed which make negative electrical contact. The speed of rotation of the drum is relatively slow. The anode is in

the form of a semi-circular cradle surrounding the lower or submerged half of the drum, the anodes being of crude copper rough cast into the required shape. As a result of an optimum speed of rotation and current density there is a remarkably smooth and even deposit of copper. The rotation of the mandrel keeps the electrolyte well stirred and has the effect of brushing away air bubbles from the surface of the cathode, and ensures uniformity of thickness of the deposited copper. Due to the surface friction between the electrolyte and the metal being deposited, a similar effect to that of rolling is obtained. A current density of 200-500 amperes per square foot may be employed, depending largely on the local condition and the cost of electric current. Any desired thickness of sheet can be obtained, it only being a question of length of time. The energy consumed works out at 1,000 k.w. hours per ton of deposited metal; this figure includes the power used in driving the shafting and auxiliary machinery.

The drum has across its surface a lateral insulating strip or alternatively a groove about $\frac{1}{16}$-inch wide. At the end of the operation the drum is lifted out of the tank and washed. A tool is inserted under the copper where the insulating strip or groove is and with a little levering the copper comes away and is peeled off as a sheet according to the size of the mandrel; large sheets can be made in the same time as small sheets and of uniform gauge. The side that was in contact with the surface of the drum presents a highly satisfactory smooth, even and bright surface. The outer surface of the sheet is also smooth and even, but has not the mirror finish of the inner surface; it can, however, easily be brought to a high degree of finish so that sheets with an equal finish on both sides can readily be produced, which has not been possible by the ordinary process. The longitudinal edges of the sheet are straight and regular, and require no trimming. This is due to the presence of a specially designed baffle, which effectively prevents lateral growths of nodules or trees. The product is equal or superior to high quality rolled copper. When extra hard sheets are required the copper is further consolidated by means of floating rollers consisting of a number of roller worked by means of a belt through levers and gearing from the main shafting. The rollers pass slowly from left to right across the whole width of the drum; they are then automatically raised and returned to the further end of the drum, when they are again lowered on to the deposit, and the cycle of operation recommenced.

Hard, tough sheets are produced in this manner which can be used for spring contacts in place of phosphor bronze, with the added advantage of the high electrical conductivity of the pure copper. An interesting application of this process is in connection with the production of bimetallic articles, for example, copper tubes having an inner lining of nickel, in which the adhesion of metals is so good

that subsequent drawing not only leaves them *in situ*, but causes the relative thickness of the two metals to be retained.

Copper sheet faced with tin, nickel, or any other metal of any desired thickness can also be produced, stampings and spinnings being made from such sheets without any sign of the metal separating. As has been indicated, the process is rapid, high quality material being produced in a very short time at a low cost. Comparatively small units—for example, a plant producing five tons of deposited material per week—can be worked economically and efficiently, and further units can be quickly added to increase the output. Any or all of these units can be shut down or restarted at short notice without the serious loss that occurs when a furnace plant is stopped and subsequently restarted. No highly skilled labour is required, the process is clean and is one of precision, and the plant required is not costly. Thin sheets, tubes and fine wires can be made costing very little more than the heavier gauges. In the case of ordinary methods of rolling and drawing the extra costs of making fine wires and thin gauges increases at a rapid rate as the gauge decreases. The crystalline structure of electro-deposited copper is at right angles to the cathode surface. Advantage has been taken of this fact for the production of wire.

Wire.

Many attempts have been made to produce wire electrolytically, but have not proved a commercial success, chiefly due to the growth of trees and nodules. The processes that have been tried for the production of copper wire can be divided into three classes :—

(1) A travelling cathode of fine wire which is thickened up by electro-deposition of copper, which is then reduced by passing it through drawplates—such as the process of Sir Wilson Swan.

(2) The production of copper cylinders or discs, which are cut up into strips or spirals—such as the process of Elmore.

(3) The electro-deposition of copper in the form of strip deposited on a thread or strip wrapped round an insulated revolving cathode—such as the process of Saunders.

The difficulties met with in such processes have been overcome by taking advantage of the crystalline structure of electro-deposited metal, which crystallises at right angles to the cathode surface. If a V shaped scratch or groove is made in the form of a spiral round a cylindrical cathode, the copper crystallises in a V shaped groove in the same way as metal cast at right angles. A sheet of metal deposited on such a pregrooved mandrel can be readily unwound as a square wire, dividing in the thickest part of the deposit. The wire thus produced has two small fins. These fins can be readily removed or drawn down in a single wire drawing operation. In this way wire of exceptional purity and high electrical

conductivity can be produced. A modification of this process consists of electro-depositing a strip $\frac{1}{4}$-in. or more broad with a weak line of cleavage produced as just described, the strip is then passed through a splitting machine thus producing a square wire without any fins.

Iron.

For many years iron has been deposited as a thin film on the surface of printing plates to give them a harder and more durable surface. During the Great War the electro-deposition of iron came into considerable use for building up worn parts of machinery, and as is often the case this was brought about by accident. Some large gauges were being made for submarines and several of them were undersized, the scrapping of these meant loss of time and money, so they were built up by electro-depositing iron, and proved quite satisfactory. Workshops were put up in France to build up worn parts of motor cars, gun fittings and carriages, and other parts of machinery; and the process has been considerably developed since, nickel being used in the same way where hardness is required.

The deposition of iron presents some difficulty in that ferrous salts are most desirable for electro-deposition, but the rapidity with which they oxydi e to ferric salts and the consequent increase in acidity of the solution has been a source of difficulty, but with the recent more accurate methods of checking the acidity, keeping the solution in the ferrous condition by the addition of ferrous carbonate, and by circulation, this difficulty has been overcome.

The presence of occluded hydrogen makes the iron very hard and sometimes brittle, but this can be lessened by having charcoal in suspension, or by subsequent annealing, though to remove all traces of hydrogen requires a temperature nearly to melting point. From time to time attempts have been made to produce electrolytic iron sheets and tubes, but difficulties have been encountered due to instability of the electrolyte, formation of nodules and the fact that the iron was brittle and had to be subjected to heat treatment to make it malleable.

A plant has been erected in the South of France for making tubes that are used for gas bottles for aeroplanes, and also for hydraulic power transmission as tubes of pure iron do not corrode or pit so readily as steel.

Zinc.

The application of electro-deposition to zinc has rendered good service to the Admiralty and Mercantile Marine for the detection of flaws and defects in boiler tubes. Such tubes are flashed with zinc by electro-deposition after they have had the scale removed by pickling. When coated with zinc, flaws can be readily detected. Imperfect boiler tubes are thus detected at an early stage before

incurring the expense of assembling. This practice also has the advantage that the tubes are protected during the time of erection and testing.

Zinc is also refined by electro-deposition. The electrolytic cells being fitted with lead anodes and aluminium cathodes, which was the original method developed in Cornwall in the year 1899. It was not until the Great War that necessary economic conditions arose to bring the process to a large production stage. Seamless articles such as cylinders and cases for primary batteries may be electro-deposited in zinc.

Lead.

Lead is a metal very readily electro-deposited. The refining of lead is an extensive industry; for this purpose a flourosilicat solution is mostly used. Lead deposition is also used for electro-plating to coat metals that are to be in contact with sulphuric acid such as accumulator work. For this purpose a lead perchlorate solution is mostly used, Peptone is generally added. A current density up to 20 amperes per square foot may be used.

Parabolic Reflectors.

Another practical use of electro-deposition is the production of parabolic mirrors for searchlights and headlights. Such metal mirrors have great advantages over glass ones, they are lighter and have the advantage that, if struck by a bullet or other missile, they can still render good service; they will, no doubt, entirely supersede glass ones.

The plant for making such mirrors includes a vat in which is rotated a ring suspended on a spindle to which is attached a glass or metal mould or matrix on which the metal is deposited. The mould, if of glass, is first silvered chemically and then the backing metal deposited on it, and when the desired thickness is attained it is transferred to a tank containing warm water which is gradually heated. This slightly expands the metal, which enables it to be removed from the matrix or mould without any distortion, and with a surface equal to that of the glass mould on which it was deposited. The mirror is then faced with a non-tarnishable metal such as palladium or rhodium.

Nickel.

Nickel has for many years been used where a hard plating was required, as for motor cars, etc. In this industry it is now used chiefly as the undercoating for chromium plating, and in the nature of the underlying nickel plating lies the secret of the durability or not of the chromium plating. For many years it was thought necessary to use a double salt of nickel as the chief constituent such as nickel ammonium sulphate, and this was the basis of all nickel plating solutions, but it has more recently been found that

a solution composed of nickel sulphate as the chief constituent gives a more rapid and ductile coating.

Chromium.

Chromium plating has become within the last few years an important industry principally used for plating car fittings, gas and water fittings, and many other articles in constant use. A few years ago chromium plating was known only to scientific investigators, but to-day it is commercial practice. The nature and character of the deposit have caused it to be established as an industry in spit of the difficulties encountered—its high non-tarnishable polish, resistance to corrosion, and its extreme hardness, making it invaluable in the motor car industry, domestic appliances, and engineering, generally where a hard surface is required.

One of the chief difficulties encountered in chromium plating is its low "throwing power" or inability to produce an even deposit on irregular surfaces, which necessitates the use of a high current density, and the use of subsidiary anodes for certain articles with deep recesses.

Chromium plating has been found very inclined to flake or peel off, but this is largely due to the condition and nature of the underlying metal which is usually nickel. It is now found that if a soft deposit of nickel with the minimum amount of hydrogen and with a high polish, there being no film of oxide on the surface is chromium plated, the plating will be quite adherent. In the case of iron or steel a preliminary coating of zinc by the sherardising or cementation process has been found to form an excellent base for chromium plating.

Cadmium.

Another metal that for years was only of theoretical interest and has lately attained considerable use is cadmium. Electro-chemically it lies nearer to iron than zinc and should therefore be less liable to corrosion. Cadmium is readily deposited, has a good throwing power, and a pleasing silvery white appearance.

Cadmium is generally deposited from a cyanide solution, and there is a wide range of free cyanide permissible, cadmium anodes being employed. The chief drawback to cadmium plating is the ease with which it is marked, and the difficulty in polishing irregular surfaces, as the coating is quickly removed from the prominent parts. Silver and cadmium alloys have been successfully deposited, the advantage of alloying cadmium with the silver is that it does not tarnish so readily, and in certain proportions is harder than silver.

Automatic Sheet Coating Process.

A very recent development in electro-deposition is an automatic and continuous process for pickling and coating steel sheets, of the

usual sizes used in the tin plate industry, with zinc, brass, lead, tin, etc. Such sheets are known as tin plate substitute, and have the trade name of Sherrite Steel Sheets. The plant consists of a series of tanks in which the sheets are pickled, cleaned, and coated with any metal, to any predetermined thickness automatically, at any desired rate consistent with labour conditions, say, a sheet per half minute. The sheets are not touched from the time they are fed into the machine and carried through by means of rollers until they emerge coated and ready for packing.

The advantages of zinc coated sheets are that they are cheaper, do not rust like ordinary tin plate, and can be stamped without lubrication. They can have a bright or matt finish, the matt finish being very suitable for printing. Another advantage of the tin plate substitute is that the raw cut edges do not rust like tin plate. Such sheets have been exposed to the weather for months without showing any signs of rusting, whilst tin plate rusts badly in a few days, due to the fact that zinc is electro-positive to the iron and tin electro-negative.

Electro-deposition of Rubber.

Before leaving the subject of electro-deposition I would like to mention the electro-deposition of rubber direct from latex by making the mould, or the metal to be coated, the anode. Inner tubes for bicycles and other articles are now being electro-deposited commercially. A process is being developed for coating sheets with rubber electrolytically.

Discussion.

Mr. H. C. Armitage (Member of Council) : This deposition of metals has, I think, a wonderful future. At the present time everybody engaged in production, whether of lamps or wings for motor cars or anything else, is seeking methods of rust prevention. Mr. Coles' remarks have been quite a revelation in letting us know what wonderful strides have been made ; in fact I have been told many times during the last few months that a lot of the things which Mr. Cowper-Coles has dealt with were yet impractical. Is it to be understood that the zinc depositing process is similar to the sherardising process ? Before proceeding further, would you distinguish for us between the electrolytic and sherardising process ?

Mr. Cowper-Coles : The process referred to for coating large sheets is electrolytic. So far as my knowledge goes, sherardising has not been applied to large sheets. It presents difficulties. The illustration I showed with the vats was entirely for electrodeposition, with a very high current density, so that the sheet could run through rapidly.

Mr. Armitage : Another field which Mr. Coles has not mentioned is the covering of metals with tin ; for instance, soldered tank or container parts, radiator parts, etc., where pieces have to be soldered together. We have for a number of years, been electro-tinning such pieces, but have found with the electro tinning process (possibly due to our rapid or careless way of handling it) that our experiments do not give us the same good results as actual hot tinning by hand. This was explained to me by an advocate of hot tinning, that electro-deposition only interlocked its molecules inside the molecules of the material on which were depositing tin, whereas the hot tinning process actually makes atomic amalgam with the material to be tinned. This was borne, put by actual results in tensile tests with soldered joints. I should like to know whether Mr. Coles confirms this, or whether electro-tinning ought to be expected to be as secure to the metal as hot tinning ? I was particularly interested in the remarks Mr. Coles made regarding chromium plating on steel. That, I have always understood, necessarily consists of putting a copper plating on steel, then putting a deposit of nickel on top of the copper and then adding a flash of chromium on top, but I have been informed that in America that process has been dropped because they actually find that the steel does not stand up to service as well as brass covered with nickel plate and a thin coating of chromium. I should like to know if Mr. Coles has any results of a zinc coating process followed by nickel and then chromium ?

Mr. Cowper-Coles : The sherardising process is not a surface plating, the zinc enters into the steel and forms a zinc alloy, which is an excellent base for direct chromium plating. As regards tinning, I believe the difficulties referred to can be largely overcome by carefully controlled conditions. If an electro-deposit is subjected to an after treatment of heat at a low temperature an amalgam takes place, which is one of the reasons why Sherrite sheets are so successful, they are subjected to an after heat treatment, so as to get an amalgam between the two metals.

Mr. Thomas : Most of the articles described to-night have been small articles. Has any success attended the chromium plating of large articles, like steel castings weighing, say, six cwts., where they would require to be plated on the machined parts ?

Mr. Cowper-Coles : No, we have not had any experience of such large articles, but if the necessary plant were provided, I do not see why large articles should not be as successful as small. The process described has only been applied to motor car fittings, and similar comparatively small parts.

Mr. Blackmore : Is this roller process used on the drum necessary for all depositing processes to get a fine surface, and does it limit the process to simple surfaces, or can an intricate surface be coated with various metals successfully ?

Mr. Cowper-Coles: Irregular articles can be coated, when rollers cannot be applied, but the same results can be obtained to a considerable extent by rapid movement of the electrolyte. With a sufficiently rapid movement a fine smooth deposit is obtained at 200 to 500 amperes to the square foot, or even more.

Mr. I. H. Wright: I am not directly interested in plating, but in building machinery. At the same time there is an opportunity for a little further exploration on the lead plating of bolts and nuts. Bolts and nuts work loose through imperfections of threads, etc., and it seems to me that possibly the deposition of lead on the surface of threads might considerably increase the frictional qualities of the threads and make bolts safer in use. I should like to have Mr. Coles' opinion about the difference in holding qualities of bolts covered with a plating of lead.

Mr. Cowper-Coles: We have not had any experience of the extra grip obtained by lead coating. I have doubts whether it would be really successful in practice, because I think the lead would be screwed off—it is so soft.

What we have found very successful, for bolts and nuts, which really prevents the nuts becoming loose under ordinary conditions, is to sherardise the surface. This gives equal thickness of coating on the bottom and top of the thread. Electro-plating piles up on the top of the thread, sherardising gives a matt surface which holds the nut very tightly. It can at any time be taken off, but it does not work off. That has been thoroughly tried out and proved successful. One of the difficulties has been that the thickness had not been properly controlled, and some nuts were tighter than others. Under proper conditions accurate thickness of coating can be ensured.

Mr. Riley: In the first slide the lecturer showed us nodules and various degrees of acidity in his sheet copper. What percentage or how many ounces per gallon of acid has he found best for his smoothest coating?

Mr. Cowper-Coles: About 10 ounces of acid gives excellent results, but it varies according to the product being made, and the speed of rotation employed.

Mr. H. G. Ramsell: In reference to sherardising prior to chromium plating, the article is prepared by polishing or buffing for the sherardisation process, and then you get a kind of rough or matt surface on the sherardised part. What is the best way to treat a Sherardised finish prior to chromium plating?

Mr. Cowper-Coles: If you require a very brilliant chromium, then the sherardising has to be polished. In carrying out the sherardising process with chromium plating, what has to be aimed at is to obtain a zinc-iron surface, because you cannot apply chromium plating directly on to a zinc surface and obtain good adhesion.

The obtaining of this zinc-iron alloy can be largely controlled by the temperature.

MR. R. H. YOUNGASH (Section President, who presided): Some of us are interested in the question of cutting tools, and I should like to ask whether you can hold out any hope that we might be able to deposit tungsten on to steel tools in such a way that we can get something of the effect of the modern tungsten-carbide tools, without the trouble we have with pieces coming off. Is that within the realm of possibility?

MR. COWPER-COLES: I have not brought any samples of tungsten deposition here to-night, because if one had dealt with all the metals one could not possibly cover the ground, but we are busy experimenting with tungsten, and have obtained some excellent deposits. We have been considering it from the point of view of protective purposes, more than hardening.

MR. S. A. BROWN: In regard to the illustration given of building up gauges, I would like to ask, must the details be cylindrical, and also what is the machineability of the deposit after it is put on?

MR. COWPER-COLES: A cylindrical shape is not necessary for building up; almost any shape can be built up, and the deposit can be machined ground or filed.

MR. J. W. BERRY: What is the relative cost of electro-depositing zinc, as compared with that of ordinary hot galvanising? I was very interested in the thin strip. Is there any limit to the width of this strip that can be deposited, particularly in regard to steel? One of the bugbears of the steel industry to-day is the production of shim steel. It often limits production enormously if you have a large consignment of shim steel put through the rolls. When you think in terms of .001 to .004 it becomes a serious problem. There is a possibility that by electro-deposition one might quite easily compete successfully with the rolled material.

MR. COWPER-COLES: There is one great advantage of electro-deposition. You can deposit a strip .002 thick, four feet or five feet in width. As regards the cost of depositing zinc, that is now reduced to a low figure. It depends, of course, on the cost of electrical energy, but an average figure is £4 to £5 per ton of zinc deposited. Zinc being only £12 to £15 per ton shows a saving as compared with tin.

MR. W. G. GROOCOCK: Every time I come to one of our meetings my major impression is "how little I, personally, know of the many processes involved in production engineering." Our subject to-night, "The Electro-deposition of Metals," is a case in point, and after listening to an extremely interesting lecture on this subject, I feel that while there is a big future for this process in production engineering, we as production engineers have only an elementary

knowledge of its possibilities. In our everyday work we find problems and difficulties when we use the process. Some years ago we had some trouble with the electro-deposition of tin. A number of small copper components had to be soldered, and prior to soldering they were tinned electrolytically. It was found to get the best results in soldering, the electro-tinning should not be done too early. Oxydation seemed to be the trouble. When the articles were soldered within three or four days of being tinned, soldering was easy, but if delayed then the best results were not obtained when soldering. I should like Mr. Coles to give his opinion as to whether this was due to the formation of oxide, or whether our process was at fault.

Mention has been made of rust prevention. We have tried many methods, but electro-deposition of cadmium seems the best. Many of the articles we wish to protect are irregular in shape with internal surfaces, and some of the metals tried fail to get on to these inner surfaces, while cadmium seems to deposit fairly well. I would like to hear Mr. Coles' opinion on this problem of inner surfaces and protection. On the question of chromium plating, our experiences have so far been disappointing, the few experiments I have made have been attempts to retrieve plug gauges by building up and regrinding to size. In each experiment we have met failure due to the flaking off of the plating. I have not tried this method lately, and I would like to ask Mr. Coles whether there have been any improvements in the method during the past twelve months.

Mr. Cowper-Coles: With regard to tinning, the difficulty, as has been pointed out, can be overcome, as the tin ought not to oxydise in that way if it is deposited under proper conditions. It was evidently porous. As regards chromium, great advances have been made within the last twelve months, and by combination with the sherardising process difficulties of adhesion have been overcome. A variety of objects can be made by electro-deposition, and as there are not limitations due to casting, stamping, or spinning the design can be largely modified often with great advantage.

A vote of thanks to the lecturer concluded the proceedings

PRODUCTION METHODS FOR SMALL QUANTITIES.

Paper presented to the Institution, Glasgow and Eastern Counties Sections, by Wm. Buchanan, M.I.P.E.

ALL manufacturers, works managers, and departmental foremen have their moments of doubt and misgivings, as well as those moments of bliss when all is going well. The blissful moments are, alas, getting exceedingly rare, and as a natural sequence those allotted to doubt and misgiving are increasing. Business is bad and expenses are high. Production has beaten the salesman, and that upon which money has been spent will not in its turn produce money, and thus pave the way for further business. The works of the manufacturers are humming with activity only to a limited degree—much more could be done if only orders could be obtained; but as the possibility is somewhat remote, all that can be done is to mark time, and hope for better days.

The manufacturer contends that if he does not earn money, he cannot spend it. And when it is suggested that now is the time to overhaul his organisation, and put his factory into fighting trim, he points with melancholy pride to what his organisation has already achieved, and to what straits it has reduced him. " Four years ago," he states, " the factory was thoroughly reorganised, and we spent a lot of money. At that time, however, we could well afford it, for our books were filled with orders, all obtained at a very good price. To meet the demand it became necessary to extend—we installed a number of up-to-date machines and paid our operators good wages. We introduced specialist departments—rate-fixing, progress and the like—and after a time we were able to quote for further work, and to meet deliveries. We were proud of the organisation of our production side, for it effectively silenced the importunities of our salesmen, who had for some time been openly boasting that they could sell faster than we could produce. After a while, however, it became necessary for us to speed up our selling organisation, for production was still forging ahead, and we began to accumulate stocks. We never doubted that, once the selling side had been raised to the same pitch as the production side, the intake would still further increase, but the high water mark had been reached, and the slump brought all our schemes to nought. Like everyone else, we accepted the inevitable, and slowed down until the time came when we felt we could again venture to move.

Ipswich, October 11th, 1932. Glasgow, November 19th, 1931.

When this time came, we considered it the better policy to concentrate upon the selling side of the organisation, and to give it a fair start we reduced the selling price of the commodity. Our salesmen did obtain orders, but they were pitiably small, and the position to-day is that our production organisation is much more than equal to any demand likely to be made upon it. In these circumstances, how can it pay me to spend more money in further perfecting an organisation that is already more than sufficient for the need ? "

This is the spirit that is abroad to-day, and the production organisation of the factory is receiving scant attention. The necessity to reorganise is realised only when the volume of business shows up the incapacity of the factory, and there being plenty of money about, new schemes are devised and put into operation. The fact that there are more difficulties and a greater wastage when an attempt is made to organise during a busy season is quite lost sight of ; the task of catering for the necessity is entered into whole-heartedly, principally because there is money coming in, and therefore some of it can be spent.

Yet the fact that orders are coming in only to a limited extent is surely proof of something being wrong, and of a necessity that must be catered for. It may have been true a year or so ago that the world was saturated with buying, and that sales could not be effected, no matter what inducements were offered, but is this true to-day ? The world is again eager to buy, but now it has a finer perception of value, and it is because that finer perception is not realised by the manufacturer that more business is not being done. We must bury in oblivion our absurd war time and immediate post-war notions of what constitutes value, and cater for the needs of the present. And it is upon these lines that we must organise. We must give value for money, and we must plan our production organisation to enable us to do this. During the stagnant period we have the opportunity of dissecting our factories, improving methods, and overhauling plant. This does not mean merely the removing of one department to another locality, the substitution of one operation for another, or the superseding of an old machine by one of more modern design. It means a thorough investigation of our factory as it stands, and of the commodity we are producing ; and it will be found that drastic changes are necessary in both instances. The development of the principal theme, in its relation to industrial efficiency, renders necessary the exposition of a scheme of workshop organisation, and in the present lecture the scheme is unfolded in detail.

The degree of efficiency attained by the factory is governed in no uncertain manner by " production planning," and no phase of the modern factory organisation has received more attention than this.

It is obvious that, to promote real efficiency, the capabilities of the existing equipment must be extended, and no new purchase should receive consideration until this has been done. It is useless for the production manager to protest that he could do better with new equipment, for this is perfectly obvious ; but before further expenditure is sanctioned the management must know that the maximum is being obtained from what is existing, and that that maximum is not enough.

It is difficult, indeed, to assert that the peak has been reached, for ingenuity has the knack of giving the lie to the assertion. Under certain conditions the maximum is quickly reached, but then conditions are subject to change, and the change has the effect of increasing the maximum. In the first place, the methods of manufacture may be quite elementary, every detail comprising the unit being made in the factory. On these lines the maximum output may equal fifty sets of details per week, but if it is decided to purchase certain details from outside, then with the equipment freed by this procedure it is possible to handle the larger quantities of other parts, with the result that the maximum is increased to, say, seventy. Improved methods of manufacture made possible by the provision of up-to-date tools and jigs may further increase the maximum to ninety, and the introduction of a carefully devised bonus system may bring the weekly production figure well over 100.

It would now appear impossible to increase further without new equipment, and the latest figure must of necessity be the peak. It may be so, but it is by no means certain, for action may now be taken in the direction of stampings or a similar process, devised for reducing machining to a minimum. It is obvious that such action on a fairly large scale will once again increase the capabilities of the manufacturing departments, and it is safe to say that the output of the progressive factory can, in a few years, increase 400 or 500 per cent., and this with comparatively little additional capital outlay.

It may be argued that such an increase is possible only in the factory where the methods in the first instance are so elementary that even a slight attempt at reorganisation cannot help but increase output considerably, but if this is the case, then the methods favoured by many so-called up-to-date concerns are extremely elementary. The truth is that no matter what methods prevail in the factory, these can be improved upon, within limits, and the reason that one concern forges ahead of the others is because the management of that concern realised the truism, and is continually effecting improvements.

Production planning, to be really effective, must commence with the design, and if the design has been in existence for some years it must be subjected to a drastic overhaul, and the specification

revised to meet the conditions of the factory equipment. It is usually the case (in the small factory, at all events) that the design is the fancy of the inventor, and the actual means for producing the finished part is rarely considered.

When a new product is about to be put into process of manufacture, co-operation between the designer and the production engineer will enable production planning to commence on a high level, as a clean slate is in evidence, not disfigured by the lines representing the activities of those who have gone before, which lines are often an obstruction bristling with difficulties. But if, on the other hand, the design is old, and the product is regarded as more or less standardised, the lines on the slate are clearly discernible, and must be obliterated before progress can be made.

The drawing of every component part must be scrutinised, and the necessary modifications made. The part as it exists may be satisfactory from one standpoint, but not from another, and so the problem must be attached. Many factors must be taken into consideration, and the changes must not be effected lightly, for the product is really an assembly of a number of sub-assemblies, and few, indeed, of the parts stand alone, in the sense that no other part is affected by an alteration. It is not even sufficient to consider under one heading the whole of the parts comprising one sub-assembly, for that sub-assembly may engage with another, and changes of a beneficial character here may have untoward effects elsewhere.

Assuming that a perfect understanding exists between the designer and the production engineer. it should not be difficult for the latter to map out the course of manufacture. He has a fairly comprehensive knowledge of the capabilities of the factory equipment, and knowing the expectations of the management in regard to output, he should be able to plan first broadly, and then in detail. It has been agreed that the equipment is capable of meeting the demand subject to the provision of jigs and tools in certain circumstances, and in the broad sense, at all events, there should be no difficulty in ensuring an equitable distribution of work throughout the manufacturing departments.

It is assumed that a bonus system in some form will prevail. The payment for production work on a flat hourly rate is being discarded even in the smallest of factories, and in its stead is being instituted a method of payment which provides an incentive to the operator. There is no gainsaying the fact that a bonus system of payment is necessary to ensure economical production, as with it output is increased, manufacturing costs are reduced, and a better feeling prevails in the factory.

This being the case, the advantages of an " incentive " are obvious, but the reward must be there. Some firms adopt operation

planning and fix rates, and then, when these have been in operation for a few months, go " all-out " for rate-cutting on the score that the workers are earning too much. Others fix the rates at a figure that will only allow the man to earn a little over his flat weekly wage, no matter how hard he works, and as may be expected, he soon ceases to strive after the impossible, contenting himself to do just as much as will enable him to keep his job. Other firms again institute a complicated type of bonus system, and the working of this not being thoroughly understood, a good deal of unrest and discontent is speedily apparent.

The small manufacturer will do well to ignore these complicated systems, and adopt a simple and straight-forward scheme which is easily understood by the operator.

Rate-setting that yields abnormally high results by way of bonus is obviously uneconomical, and it is at once apparent that the persons responsible for the rate knows little of the operation, or of the facilities provided. It is not enough for the rate-setter to know all about the theoretical capacity of the machine by means of feed and speed calculations, but he must also know the capabilities of the machine in relation to the specific job, the special facilities provided for that job, and the capabilities of the operator. This latter is most important, for it is in many cases an unknown quantity. Many progressive firms to-day appreciate this, and are endeavouring to sound the depths of individual capability by means of vocational selection. It is an endeavour to quicken the leanings of the individual, and to develop his potential capabilities in the direction to which they will the most readily respond.

Every person has a "leaning," and could that leaning be detected and fostered, the highest state of efficiency would be the result. Unfortunately, the expressed desire of the individual is not always indicative of the primary talent, for even the most intense interest one evinces in a certain direction will not always produce capability which equals 100 per cent. efficiency.

This capability must be sought for, and may be found through the medium of vocational selection. Briefly, it is getting the right man for the job, or conversely, getting the job right for the man, and unless the capabilities of the operators are known, operation planning can never give the best results.

The production system which is about to be described, is not in any way theoretical, but one which has been successful in maintaining the highest efficiency in the manufacture of small quantities. This scheme was introduced in the first instance to ensure the highest production on small quantities, but later it was applied successfully to the manufacture of quantities up to 500 units. It is needless to point out that from a production point of view, it is extremely difficult to get the best results from small quantities.

The time spent in obtaining raw material, drawings, tools and jigs is often charged against the machining time. When large quantities have to be produced, this is not so obvious, but in the manufacture of small quantities the time required for this work is often greater than the actual machining time. To overcome this, it has been found necessary to prepare the entire job for the operator before he actually commences the work. The raw material is laid at the machine along with the drawing, jigs, instructions and routing card before the operator is finished with the job on which he is working. It will readily be understood that saving in time is considerable as the operator has simply to pick up the instruction card and proceed with the manufacture of the article to the drawing which is lying ready to his hand.

An endeavour is always made to carry on with same class of material as that previously machined. Saving in this is obvious

The entire work's system is controlled from a central office which is called the Progress and Production Department. The works manager has his office in this section along with the specification department, production and rate-fixing section, progress and stores. The office is situated in a central position, and the stores are built close to the office. The stores section is in direct communication with the stores.

The System Briefly.

When an order is placed with the firm, it is sent to the contracts department who distribute one copy to the works, and one to the drawing office. This is an actual copy of the contract, so that all particulars are available for the drawing office, and the works executives. When the drawings are completed a tracing list is made up by the draughtsmen, and delivered to the progress and production office, where the specification of materials is made out. From the specification the works orders are detailed, and sent to the feeder departments and production section.

The routing, time and instruction cards are completed by the production section, and when the raw material is delivered to the stores or department, these cards are released to the particular department concerned with the production of the unit. The assembly, routing and time cards are issued when the machined parts are received in the store. The progress department keep a record of the progress of all parts until they are finally completed and dispatched.

Classification of Work.

Jobs are divided into classes, and each class has a different range of numbers.

(1) *Job Number, e.g.* 98996. Under this heading is included all work which is not standard, and which is manufactured in small quantities.

(2) *Batch work, e.g. X*.1816. This classification is used for any unit varying from six to fifty complete sets. The job number for this class is proceeded by " X."

(3) *Comco parts.* This is an abbreviation of common components, and covers the manufacture of all parts which are common to many jobs. These parts are manufactured to their own definite comco number, and are always available in the store. Quantities for manufacturing purposes vary from twenty-four to one thousand, but the average is about one hundred.

The numbers are prefixed by the first letter of the article being manufactured, e.g. V50 would represent $2\frac{1}{2}$ in. discharge stop valves.

(4) *Renewals and repairs.* Numbers for all repair and renewal parts are prefixed by the letter " R," and their own original job number follows the letter, e.g., R.200.

Specifications.

The specification is the foundation of the entire system. If this is not correct to the smallest unit, then all other parts of the system, no matter how perfectly they may synchronise, will not correct a mistake or omission. That is, if a part is missed out or wrong material ordered, then the system will only produce what is on the specification.

When the drawings and tracing lists are completed, they are checked by the chief of the works order department, who then issues the necessary instructions to the girls responsible for making out the rough draft of the specification. The official date for delivery is obtained from the order, and all intermediate dates for the various operations are arranged accordingly. If any unforeseen difficulty arises which will prevent completion by the estimated date, these are immediately reported, and our customers are informed by letter that the delivery date can not be adhered to, along with the reason for alteration.

The progress department file all orders to the works under their delivery dates, and when the new order is made out it is placed under the month marked on the specification. This enables the production department to place the orders in the proper category ; for urgent deliveries or otherwise.

The specification proper is then proceeded with commencing with the first tracing. All units are detailed giving name of part, symbol, material, pattern number and comco number. The feeder departments which supply the raw material, the departments concerned in the manufacture, the date of delivery and machining dates are also given. The sub-assembly, assembly, and tests are also noted so that orders are issued as required. This, of course, depends on the method of machining, and is settled by the production section. This copy of the specification which is written in pencil,

is then sent to the stores department who analyse their stock requirements, and allocate any excess material which is suitable for the job. Location of any excess part is entered in the specification by the stores department.

The official copy is then typed out with a duplicating ribbon, and when completed, one copy is reproduced on a stiff card, and is used as the official progress record. The first copy is filed with the official order, and one copy is used for costing purposes. This latter differs only from the specification in that the columns are used for weights and costs in place of departments, etc. The specification is then handed to the typist who makes out official orders for all parts.

Works Orders.

The works order forms are fastened together in triplicate, and each form contains six orders which are perforated to facilitate tearing off. This adds considerably to speed and accuracy in typing, and only one checking is required. These orders are taken from particulars as given on the specification. They are issued in triplicate for castings ; one copy being sent to the following sections :—*Pattern shop, foundry progress section, production section.* This latter copy is the original, and typed with a copying ribbon. Three copies are also made out for purchased material, and are distributed to the purchase department, stores section (to identify parts when they are received) and production section.

In the case of bar material or forgings, orders are sent to the Smithy or stores, and production section. This form has been so designed that all necessary particulars are included on the top and right hand margin. The routing and time cards are duplicate in so far that the cards are a duplicate of the original order. At the bottom of the order, all comco parts are filled in, and these are delivered from the store on the presentation of the routing card.

Production and Ratefixing.

These operations have been very successfully combined, and the production engineers who make out the machining methods, also estimate the time allowance. This is an excellent arrangement, provided a staff with the necessary experience is available. A thorough grounding in machine shop practice is essential, and it is desirable that the executive should have experience in the design of jigs and tools, along with training at demonstration work. This last point is, in my opinion, very essential, as it is good practice to demonstrate certain jobs. The demonstrator finds out the exact limits of the various machines and tools, and obtains the required knowledge for setting times for all manipulative work, which is most essential in working out the correct time allowance. This part of the system is based on what is termed the master card. This

card is filed under tracing number, and item letter of the part. It shows the operations necessary, the department, the machine to be employed, and the time allowance for each operation. There are three columns for time allowances, this being necessary for varying quantities, and also eliminates the repeating of calculations.

All job numbers and dates for which the parts have been issued are recorded. This is of great value when consideration is being given to new methods, and the number which has been manufactured over a certain period has to be obtained. This card is also the record of the issue of routing and time cards. The actual time taken for each operation is recorded on the back, with the result that the management can see at a glance the actual time required for any particular unit which may be quoted for. Any special instructions which have to be issued are also recorded on this card.

A card index is kept under the name of the part. The master cards for all similar parts can be found with a minimum of trouble. This is absolutely essential when a change of method is made, as the change may effect a dozen similar parts differing only in size. It is quite obvious that if this is not carried out the old method may be issued at a later date for some of the parts.

Methods to be used.

Methods are always under review, and to maintain efficiency, the production engineers are encouraged to visit the various departments as often as possible. While in the department, it is their duty to time study any job, and to assist the foreman or operator wherever possible. Operators are encouraged to raise questions on the methods made out, with a resultant higher production on many jobs. Where new methods have been introduced, it is the practice of the production manager to keep in touch with all new methods, with a view to proving that the production engineers are maintaining their efficiency.

When any unit has to be machined, reference is made to the master card for a record of a similar part. If this is available it is checked and passed to a girl for completion. If no suitable record is available, or if existing method can be improved, a new master card is written out, method settled, and all particulars filled in.

In calculating the time allowance, the figures are based on the results obtained from actual demonstrations of many thousands of operations carried out during the past twelve years.

When any special jigs, fixtures or tools are made, an official demonstration is carried out. The actual work is done by a demonstrator, and is witnessed by the operator, shop steward, and a representative of the production department, who records time, speeds, etc. These demonstrations are carried out in accordance with an agreement between the management and the employees.

The actual time allowance is made up from the time taken by the demonstrator, and the formula employed is as follows :—

Actual machining time	=
Actual manipulative time	=
Tool allowance five per cent of machining time	=
Fatigue allowance, 20 *per cent. of manipulative time*	=
Contingency time allowance... ... ... *Machining time plus manipulative time*, 40 *per cent. of total*	=
Allowance for 33⅓ *per cent. bonus* ...	=
Total time allowance	=

This formula applies to the Weir Premium System only, and would not be suitable for any other system which differs from it. The above practice is only used for standard parts which are batch or comco jobs, or in other words, produced in fairly large quantities.

From these demonstrations figures are obtained which enable the correct time allowance for small quantities to be made out. Graphs for recording time allowance for varying sizes of similar parts are also used. This type of record can be used with great advantage for many classes *and different types of jobs*. Departments are arranged for particular classes of work, but this does not prevent a unit being sent to another section if a more suitable machine for the operation is available. Transport, etc., of course, is always taken into consideration. The machine number of any machine is a departmental number, and is arranged so that all machines at the end of the passages start with a constant number; i.e., first line 1, second line 21, third line 41, and so on, thus making for ease in material and tools being placed at machines. This number is not connected in any way with the plant number of the machine.

Instructions to operators.

There are two methods of giving instructions to operators. The first and most general is the instruction for the specific class of machine ; e.g., drilling. This is a standard instruction for all drilling, and for the various sizes of drills the correct cutting speeds and feeds for the various material is given.

A general instruction card on above lines for all types of machines is used, the speeds and feeds given being those used in calculating the time allowance. These are good average figures, but in some cases they may be exceeded or reduced, depending on the class of material. This variation is left to the operator in general work, but in demonstrated work (work with special bars and jigs, etc., the operator must work to instruction. It is not the practice to issue an instruction where the part to be machined is standard

and follows a definite method for similar parts. An individual instruction is only issued when the method is entirely new or differs in any way from usual method. This instruction sheet is similar in size to the time and progress card, and the main particulars are duplicated from the order.

Special Jig and Tool.

When consideration is given to a new method in which special jigs and tools are required, the time taken by the proposed method is estimated as well as the approximate number of parts to be manufactured. The total saving against the time taken without the special equipment is made up in £ s. d., and the oncost added. This enables the jig to be ordered from the jig and tool department at a certain definite figure, and if this cannot be produced at the price stated, the order is returned to the production department for further instructions. In the case of standard work, the quantity is based on a two years output.

Issuing of Time and Routing Cards.

On completion of the master card, it is passed to a girl who duplicates two routing cards, and the necessary number of time and instruction cards. When this operation is completed, the machine number, operations, time allowance, and instructions are added to the cards by a typist. These are then pinned together and filed under the job number. All the cards remain in the file until the location of materials is received from the progress section. When this information is received the location is marked on the routing card, dated and delivered to the time and progress booth in the particular department where the operations have to be carried out. The time clerk receives the cards and separates the time cards from the routing cards. The time cards and instruction cards are still pinned together, and these are filed under the machine number for the first operation. The clerk can only issue a time card for any operation when the routing card is presented. When issuing this he has to add the date and time. The time card on completion of the job will not be accepted by the time clerk unless it bears the inspector's signature.

It is the duty of the time clerk to total up all times, and make out number of bonus hours saved. If for any cause, extra time has been spent on a job, the foreman certifies this on the operator's card, and this is laid aside for investigation by the production engineer, who adds the necessary allowance. If the operator fails to earn 33⅓ per cent bonus, it is the foreman's duty to give an explanation on the card. This has given excellent results in keeping the operators up to standard, as all times are based on the average operator earning at least 33⅓ per cent. bonus. All time cards completed are returned to the cost office within twelve hours.

The routing cards are issued in various colours. These are:

For ordinary work.	*Buff.*
For urgent work.	*Green.*
For very urgent work.	*Red.*

On this card is a note giving permission to the department to work overtime to meet the date if necessary.

For replace parts.	*Blue.*
For repair work.	*Yellow.*

The class of card to be issued depends on the delivery date, and is marked on the order; very urgent, etc., as considered necessary.

Time Cards.

Time cards are also issued in three colours, but this is for a different purpose.

For all ordinary work.	*Buff.*
When extra work is necessary due to bad castings or materials.	*Blue.*
When extra work is necessary due to machining or D.O. errors.	*White.*

The different coloured time cards enable the cost section to provide, without any undue delay, the reason for the high production cost of any unit. All extra time spent on bad material is also noted to the foundry from these cards.

Additional operations form.—This is an operation which has not been made out by the production department. There are many reasons for this form being introduced; one of the outstanding ones being the fact that foremen occasionally take it on themselves to issue instructions for operations which are considered unnecessary by the production engineers. As these operations are completed before the production department are notified, no steps can be taken to counteract this habit. Under the present system the foreman fills in the form, forwards it to the production section, and if same is approved, it is signed and returned to the foreman, who in turn gives it to the operator, who presents it to the time clerk for the time card which has been made out by the production section.

Abnormal Bonus Earnings Form.

Abnormal bonus earnings are less than $33\frac{1}{3}$ per cent. and more than 100 per cent. These are used as a guide to rate-fixing results, and also used to check up any injustices which may be taking place in the various departments, due to foremen, operators, etc. When over 100 per cent. bonus has been earned, the rate-fixing is carefully checked, and if found correct, the name of the operator is noted for consideration for any reward or advances which *may be given for high efficiency.*

A form is filled up by the time clerk when an extra time allowance has been added to the original estimate. This particular report

enables the production section to investigate and eliminate the major faults which cause extra operations. These may be due to hard or heavy material, bad shaped castings, or bad rate-fixing, and a copy of this form is sent to the foundry manager, when the foundry is at fault.

Machine Record Cards.

This card records all particulars of general types of machines. These are filed under the departmental machine number, while the plant number is also recorded. This record is essential to the production engineers when time allowance or methods are being made out.

Loading of Machine Card.

Each job as completed by the production engineer is entered on a card in terms of hours work. When the time card for the operation is returned to the office, the operation is crossed out so that the amount of work before any machine is always visible. The obvious advantage of this card can be seen at a glance, as it shows at once the need for night shift or overtime.

Bonus and Time Records.

This form is filled in by the time clerk as and when time lines are handed in by the operators. The bonus hours earned are recorded on this sheet, and are totalled at the end of the bonus period, which usually is four weeks duration. This figure is used as a check on the figure of the cashier's department. The necessity of this check is that a time card can be easily misplaced or a bonus return placed against another operator's number. The form also shows the time clerk that each operator has passed a time line or time lines for a full day's work.

Bonus Percentages and Averages.

It is useful to keep a record of bonus percentages earned by all operators, classes of tradesmen and departments. This form is made out from wages sheet for each bonus period. One copy is retained in the production section and one delivered to the foreman of each department. A pen picture of his men can be formed from this by the foreman, whose duty it is to investigate the reason for small bonus earnings, and to assist these operators to improve on their previous efforts. Charts are made out from the above figures showing the variation in bonus percentages for each department. This is kept in the works manager's office with a view to informing him as to the rise and fall of bonus earnings. When a falling off in bonus is perceived, an inquiry usually results with a view to ascertaining the reason.

Progress.

This is controlled by the progress section in the P. & P. Department, and any special instructions regarding changes in delivery dates, etc., are given direct from the production manager. The progress clerk controls the work in each department. He is responsible for the loading of machines, and works in conjunction with the progress section in the P. & P. office. The main progress record is the copy of the specification made out on a stiff card which was previously mentioned. This is filed under the job number, and the dates when parts were ordered is filled in by the ordering section before the record is delivered to the progress section. When raw material or parts ordered outside are received in the store, they are located and the order accompanying the material is returned with the location and date inscribed thereon to the progress section, who fills in all particulars on the main record. The order is then passed to the production section, and this constitutes the release note for the time and routing cards. When these cards are received by the departmental progress clerk, he files them under the first machine number which is required for the first operation.

When any machine requires a job (it is the practice to have one job in operation, and one job at the machine, with all particulars) the progress clerk provides the progress labourer with one routing card, who draws the parts from the store, at the same time obtaining the drawings, jigs, tools and gauges, etc., as called for on the drawing. The various parts are delivered to the machine with the routing card. When the time clerk gives out the time card for any operation, he marks off the operation on the department progress card. This card is similar to routing card, but is filed in time and progress booth, and is the progress clerk's record of the position of the part. When the last operation time card has been returned to the time booth, he gives the department progress card to the progress clerk, who sees that the parts are delivered to the store. The routing card must be signed by the inspector before the material is removed from the department. This ensures that all parts have been inspected and are satisfactory.

The finished parts which are received in the store are again located and the routing card is returned to the progress section, where the location and date is entered in the main progress record. When the last part of a job is located, the production section receive the card which constitutes release note for the assembly or sub-assembly of the units. The location of all parts is marked on the routing card. Routing and time cards are then delivered to assembly department. On completion of assembly and tests, the parts are delivered to the despatch department, and the routing card returned to the progress section, who fill in date and issue delivery instructions to the despatch clerk. When the unit is finally despatched,

the progress section and cost section are notified. The records are then removed from the file.

Progress Chart.

A chart is used for recording progress of large contracts. This chart is compiled from the works order, and the delivery dates are shown in the following colours :—

Drawings approved.	*Red.*
Patterns completed.	*Blue.*
Castings.	*Yellow, and so on.*

This chart is kept up-to-date by the progress clerk in the P. & P. Department, and is exceedingly efficient, provided the parts are properly recorded. It will be obvious that the position of the whole work can be seen at a glance, and steps taken to speed up the production if found necessary.

Inspection.

When an operator completes a job, the inspector punches the time card with a numbered punch, and records any defective work thereon, thus ensuring that the correct bonus is paid. Should a unit prove defective in material during an operation or at the final inspection, the operator is paid 50 per cent of his average bonus, this being part of the agreement between the management and the shop stewards, so that no unnecessary time will be spent on a bad casting. If a defect appears during an operation, it is the inspector's duty to scrap the unit, or allow the operation to proceed. If there be any doubt as to which course should be taken, the job is immediately removed from the machine and an appeal made to the chief inspector.

When the unit is finally completed, the number accepted is recorded by the inspector on the routing card, as no gear will be accepted in the stores unless it bears the inspector's stamp, and the card his punch mark.

Rejection Form.

When a part is rejected by the inspector, he fills in the rejection form with the number of the operation at which the failure occurred. This is returned to the progress section who issue orders for the replace parts. This order takes the form of a blue routing and time card, the time card only being issued up to and including the operation where the part failed.

The time cards not used on the previous casting come automatically into operation. By this means a record of extra time spent due to the failure of any unit is obtained. Inspection is carried out in various methods to suit the work in progress. Line inspection takes place wherever possible, but in some cases the work has to be taken to an inspection centre. This is only done where a surface table or special gauges are required.

The Foreman.

So far the foreman has not appeared in the system. The policy when appointing a new foreman is to give him a few months training in the production section, as he is then imbused with the correct principles of production. He is definitely responsible for the quality and quantity of work produced in his section. He is actually a member of the production section, and collaborates with them in improving methods. He assists the operator if any unforeseen trouble arises. Many valuable suggestions have been made by the foremen, who are entirely free from all inspections, progress and many other details which so exasperate the real production foreman.

The foreman, as a rule, is promoted to his job on account of his ability as an engineer, and these are oftimes lost through the time involved in writing of lines and progress work. It is undoubtedly true that a clerk can do this much more efficiently than most foremen, as in the system laid out, the only qualifications required are those of being able to read the job numbers and learn where the particular machine required is located.

Stores.

The storing of parts is divided into two sections. The job number parts are located in store until required. These may take the form of raw or finished material. In this section, the class of material is always changing. The type of racks used are those which can be quickly altered if necessary, to suit changes in the work. In the case of large castings weighing over one cwt., these are delivered direct to the machine shop by the stores department, who are responsible for the receiving and locating it.

The second section is used for standard parts which are always carried in stock, and in this case they have a standard location. That is, they are always stored in the same rack or bin, and each rack is specially designed for the part which has to be stored. There are various sub-divisions in this area for castings, stampings, bar material, etc. In the case of bar material, the stores department, supply the bar cut to length as called for on the order. The cutting off machines are located in the store and are controlled by the stores department. Small finished parts are placed in specially designed trays or boxes in the department where they are manufactured, and the racks in the stores are constructed to suit these. This was adopted to protect the finished unit, and also to reduce the time taken in counting small parts. These parts are stored on the maximum and minimum basis, but this is checked by the perusal of specification as previously mentioned. This enables smaller maximum and minimum quantities to be fixed as the stores receive definite warning when any large quantities of a certain unit are being called for and issue orders accordingly. The time necessary to obtain

supplies from outside suppliers is recorded as well as the time required to manufacture any quantity produced in the works.

It will be observed that by the use of the above data great economies are effected in the number of parts which are carried in stock. In the manufacture of certain units large economies can be obtained by increasing the quantity to be manufactured. This reduction is specially noticeable when automatics are used.

Release of Material From Store.

No parts are issued from the store unless the routing card is presented for the particular unit which is required. After time and routing cards have been duplicated from the original order which was issued to the production section, it is passed to the stores department who use it as a store record. When the routing card is presented by the progress clerk to the stores and the parts are issued, the order is then passed to the cost section who record the issue of the material on the costing record.

The Costing System.

The main essentials in a costing system are accuracy and speed. All completed time lines are delivered to the cost office within twelve hours of completion of the operation and recorded against the particular job on the same day. This enables the cost of any particular job to be made out on the day of despatch, as the totals only require to be added. Inquiries are always being made as to the cost of certain units, and this enables the desired data to be furnished without the loss of time. When the necessary information has been extracted from the time lines, these are filed for reference under their original job number and symbol number, with the result that the actual cost of any part can be produced at a moments notice.

The costing material is made out on the cost specification. All weights of material are returned to the cost section in the P. and P. Department and charged against the particular job and symbol number.

In dealing with comco parts, a record is passed to the cost section and from it all comco parts used are marked off on the cost specification. When the job has been despatched, this specification is passed to the main cost department within twelve hours.

Conclusion.

The foregoing system is applied to a works employing 2,000 men, but it can also be applied to small works quite successfully. It may be that one man will make out specifications, production methods, rate-fixing, and also progress the work, but so long as the principles are kept in mind, successful results will be obtained.

Discussion, at Eastern Counties Section.

MR. M. G. WOODS asked if the system in question could be applied to small firms. He stated that in these days, when jobs had to be done at cut prices, it was necessary that the work should be done as cheaply as possible. With regard to the bonus systems, Mr. Woods asked if the foremen came under this scheme.

MR. BUCHANAN: With regard to costs, this system could be applied to small firms. He mentioned that his firm had eight girls to take care of all the ordinary work. Regarding the second question, the foremen did not participate in the bonus scheme.

MR. H. A. HARTLEY (Member of Council) said that, firstly, he was not clear as to what was actually meant by the department marked "Finished Stores" on the chart. Was it a store which was simply used for machined parts ready for assembly, or was it a store where finished machines were placed? Secondly, he was greatly impressed by the number of people which must be required on the staff to work the system which had been so clearly explained. Could the lecturer tell us how many people were employed to carry out this system? Thirdly, he had been very interested in the mention of the question of defective castings, but nothing had been said about the steps which were taken to cure defective castings, or who was responsible for finding out what was wrong. In their own works they had a committee which discussed every defect and by this means they had been successful in reducing the percentage of defects to well under 2½ per cent. He would further like some more information on the bonus system, not being clear as to what was meant by manipulation time, and the way total hours allowed was arrived at appeared to him to be very generous to the men.

MR. BUCHANAN replied that with regard to "Finished Stores," this was really for parts which had been machined and were ready for assembling. The idea of this was to prevent people getting machined parts before machines were actually ready for erecting. With respect to the size of the staff required, this was not really very big, but of course, speaking about it makes it seem large. He pointed out that they had one rate-fixer to 100 machine operators, one progress clerk to 100 operators. On specifications there were two girls working to each 100 men, with possibly three girls to 1,800 men. Duplicating time and rating cards there was one girl to 1,000 operators. He stated that there were 5,000 to 6,000 different time cards in a normal week and these were dealt with by one girl with a duplicator. Two girls filled in the departments and numbers of operators. One girl kept two typists going. One girl was in charge

of the final cards in the office. Respecting the testing of castings, this is left to the foundry section staff. With regard to the bonus system, the time allowance really means the time that the machine is working, i.e., cutting time. Manipulative time is the time the operator is working. If a machine is doing all manipulative work a man gets a bigger allowance.

Mr. Diggle pointed out that nothing had been mentioned with regard to any understanding between the works staff and the designing department. He asked what was done in this direction. Further, if a very urgent job comes in what action is taken ?

Mr. Buchanan stated that when an order is received the drawing office makes a preliminary drawing and sends it to the production department, and the production engineer looks over it and makes a list of points arising from the drawing. These points are then discussed by the production engineer, works manager and chief draughtsman. When an urgent job is received the works manager sends this to the progress department. This department is responsible for the stopping and starting of any job. The foreman does not enter into this. The progress clerk issues the necessary instructions and is responsible for the work being out to date.

Mr. Brazier stated that it appeared that a great deal of clerical and technical work had to be done before an order was passed into the shops as it had to go through about 16 departments. It appears to him that this system would not be efficient in the small factories that th y have in East Anglia. He asked the lecturer what would be the minimum number of employees in any general engineering works where this system could be worked efficiently. He stated that in East Anglia the largest number employed in any of the works would be 1,100-1,500, and it appeared that even these numbers were too small to introduce the system that had been discussed, but at the same time he agreed it would be an excellent system for larger engineering works.

Mr. F. Ayton (Section President, who presided), proposed a vote of thanks to Mr. Buchanan for his very interesting lecture and Mr. Buchanan suitably replied.

INAUGURAL MEETING OF THE YORKSHIRE SECTION.

THE Inaugural Meeting of the Yorkshire Section of the Institution was held at the Metropole Hotel, Leeds, on Monday, 30th January, 1933, at 7-30 p.m., attended by close on 100 members and visitors, including the following Members of Council, Messrs. S. Carlton Smith, E. W. Field, J. A. Hannay, L. Page, J. D. Scaife and J. G. Young. In the absence of the President of the Institution the chair was first occupied by Mr. S. Carlton Smith, Chairman of Council.

MR. S. CARLTON SMITH : Our President, Sir Herbert Austin, was expected to be here this evening to take the chair, but I regret to announce his enforced absence. In the circumstances it is my duty, as Chairman of Council, to deputise for him. Being conscious both of the honour and the responsibility, I shall endeavour to conduct the opening proceedings to the utmost of my ability before vacating the chair in favour of the President of your Section, Mr. James G. Young, M.I.P.E.

It will be necessary for me to vary the remarks I was going to address to you in order to embody some reference to the more important general aspects of our Institution, which it is usual to incorporate in inaugural speeches, and which our President would wish me to mention.

Objects of the Institution.

The Institution was founded for the study and advancement of the science of production engineering, for aiding its Members and the profession as a whole. It is devoted to both the theoretical and practical aspects of the profession, to good organisation, to scientific and practical management, to industrial economics, and the relationship between production and costs, as well as to the more obvious aims of imparting knowledge of fostering the use and improvement of the most efficient machines, tools and methods of manufacture, of furthering the education and training of the young engineer. A list of the objects of the Institution is set out in the Articles of Association, and these are well worth, not only reading, but remembering, because they are widely comprehensive.

Qualifications for Membership.

The Institution admits to its principal membership grade only those engineers who are fully qualified, but it is not exclusive inasmuch as there are other grades, commencing with graduateship. Many members in the Institution improve themselves and qualify for transfer to a higher grade.

Progress of the Institution.

The progress of the Institution has been remarkable, testifying to the appreciation of its members and others that it fills a real need and achieves the fulfilment of its aims. The present increase in membership is over 200 new members per annum, and even the rate of increase appears to be on the up-grade. At the present rate of growth the Institution promises in due time to become one of our largest and most important engineering institutions. At frequent intervals new sections are being formed in various parts of the kingdom.

It is very gratifying that this Section is now being founded in the heart of Yorkshire.

At this stage it is appropriate for me to draw attention to the fact that although the Headquarters of the Institution of Production Engineers is in London, every Section wherever situated has an equal voice in its government, with representation on the Council of the Institution.

Activities of the Institution.

Time will just permit the more important activities to be mentioned, although nothing like a full list, nor for those indicated to be adequately described. They are mainly conducted by standing and special committees appointed by Council, and include :—Finance and Development, Library, Papers and Lectures, Publications, Education, Examinations, Research, Payment by Results, Appointments Bureau, Recruitment of Apprentices and Trainees, Local Sections. Now I have left till last what I consider one of the most important activities of the Institution, namely the meetings. Here engineers meet to listen to well-chosen lectures, to take part in discussions and to exchange views and experiences. The value of these opportunities can scarcely be over-rated. The measure of success of these meetings undoubtedly depends in a degree to the extent of the advantage that is taken of them, to the amount of appreciation and to the upkeep of enthusiasm, to the maintenance of that " first fine, careless rapture," that you are experiencing this evening. It depends on leadership by the President, loyalty, good organisation and, above all, hard work by the Committee, and on loyal constant support by every member in putting in attendances themselves and bringing their friends. England expects and gets great things from Yorkshire whether in work or play (especially cricket). The Institution expects and will get great things from Yorkshire.

Last week I had the privilege of attending an inaugural function of a great highly important nature, and the last words of the Chairman, who is an eminent builder, ring in my memory. He finished by quoting : " Ye have builded better than ye know." Gentlemen, I say you have a great and true foundation—your great and beautiful structure will stand sure upon it.

A resolution in support of the formation of the new section having been adopted unanimously, Mr. Carlton Smith then vacated the Chair to Mr. Young.

MR. JAMES G. YOUNG (Section President): We are here this evening as a body of engineers and are extremely fortunate in having amongst us several past Presidents of the Institution and Members of Council. The Council of the Institution, in supporting a Yorkshire Section and taking a great interest in the Inaugural Meeting, have chosen the first lecturer very wisely, and it surely is an honour for us to find so able an engineer as Mr. T. Burness attending to give his paper, which has been so well received in other districts where the Institution of Production Engineers has local sections.

In looking round the hall I find several leading engineers and factory executives, qualified for membership in this Institution, and I am sure we are going to have a very strong section in Yorkshire.

Our aim is to create interest in all problems the production engineer has to contend with and each paper given before the Section will be carefully selected, and as often as possible, cover subjects which arise in engineering production in Yorkshire. The production manager responsible for various articles in small quantities, often single items, is at a great disadvantage in getting his responsibilities recognised. My sympathies are with the executives who supervise production in small shops that lack capital, and for others whose plant is entirely unfitted for the work they must undertake. This Institution has its doors wide open for such men, as they must have ability to be able to hold down such berths, and therefore are entitled to membership, due to the fact that they are qualified executives. To take time to explain at this meeting the function of a production engineer would be unfair to the members of our Council present, and the lecturer of this evening, but some of the duties of the production engineer are worth touching upon for the benefit of those that have thought we may only be interested in mass production.

A good production man must have some knowledge of design—not necessarily be a designer—but know enough to assist the designer to machine or produce mechanism, or part, which has been laid out on a print, drawing or sketch; very often he must make sketches, especially in small production of parts. He must be familiar with time-study, estimating, plant lay-out, knowledge of machines, materials and methods, a good understanding of the human element, and, above all, co-operate with other departments, such as purchasing, heat-treatment, inspection, material control, progress, costs, and, when called upon, sales.

In some circles we hear a lot about machinery supplanting labour. In nearly all industries if we cast our minds back, we can remember when many laborious tasks, bordering almost on cruelty, were performed by both man and beast, and who shall say that the

introduction of motor cars and flying machines, etc., has not been a blessing to mankind in general? I believe in machinery, and anticipate its wider development. Why should we not be released from the burdens of labour under which humanity has bowed for ages past?

Ages ago primitive man used simple tools with the hopes of lightening his burden, and from very humble beginnings invention after invention progressed till finally motive power developed, water wheel, then steam, followed by electricity and its easy application to man's desire to produce in quantities under better methods, and each advancing step really eases the burden of productive methods, and we must not look upon invention as a curse on mankind. We live in the age of speed, and possibly suffer from maladjustments of markets and distribution methods for the sale of our products, but we must be on our toes, more so in future than ever in the past. The salvation of our profession is everlasting research, and demand for better products which must call for ever changing ideas for machines, tools, and methods.

I look forward to the time, and I trust all thoughtful people do so, when economic changes will prevail to make possible the introduction of machinery and equipment in the Eastern countries, so that by machine mindedness many wretched burdens, called manual labour, will become extinct and the introduction of machines will raise the standard of living. The great fact is that humanity as a whole has never had its needs fully supplied. Means must be evolved to get the great mass of the people of the world to purchase machine made products. If we, as engineers, study the problem we must prepare for more intense competition by better methods of production and not become alarmed by the cries of the economists. Wider distribution is the urgent need: many intelligent minds are seeking the channels to procure this. Let us as responsible production men be ready to advise on the best methods possible whenever called upon. In conclusion I welcome you here and hope you will join in the discussion which will follow the lecture to be given by Mr. Burness. You are all invited to ask questions pertaining to the subject of the lecture.

PRECISION IN THE MANUFACTURE OF HEAVY OIL ENGINES.

Paper presented to the Institution, Birmingham and Yorkshire Sections by T. P. N. Burness.

FIRST of all let us see what the modern oil engine demands of the manufacturer. In recent years considerable advance has been made towards higher piston and rotational speeds. Mean piston speeds of 1,000 feet per minute are now quite common, and even higher speeds are well beyond the realm of experimental work. Some of the engines are 100 h.p. per line running at 300 r.p.m. It will be seen, therefore, that the materials used must be of the very highest quality to enable them to withstand successfully large temperature variations and fluctuating loads, and the workmanship must be of the most accurate description to ensure that perfect alignment so necessary for smooth running as well as interchangeability of parts. The type of engine which I propose to take for the basis of my paper is a multi-cylinder engine of about 600 b.h.p.

The airless injection engine is so well known as a prime mover and its performance proved over a number of years that power users all over the world—on land and sea—testify to its outstanding economy and reliability. I should just like to touch on the question of the operation of these engines. The engine is of the four cylinder type. During the outstroke of the piston following the exhaust of the products of combustion, pure air is drawn into the cylinder and during the instroke this is compressed to about 450 lbs. per square inch. The compression temperature is sufficient instantly to ignite the oil which is injected into the cylinder at the right moment, and the resultant pressure drives the piston forward. On the return stroke the exhaust gases are expelled. The oil is injected by a positively driven spill valve type of fuel pump actuated from a side shaft. Upon entering the cylinder the oil is split into a finely divided spray by an atomiser automatic in its action. The fuel pump is of the packingless type and both the pump and the atomiser demand for their successful operation the greatest precision in workmanship. Starting is by compressed air to all cylinders and this method gives instant starting in any position with six or more cylinder engines and reduces to a minimum the barring necessary to start engines with a less number of cylinders.

The air control valve operated by the camshaft automatically admits air to each cylinder in correct sequence. The starting lever is coupled to the fuel pump in such a manner that the pump and

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Birmingham, January 18th, 1933; Leeds, January 30th, 1933.

compressed air cannot be brought into action together, thereby simplifying the operation of starting and giving complete safety. The air supply is from a suitable receiver charged up to 300 lbs. by a small auxiliary compressor unit.

Now let us take the principal components and follow them through the manufacturing process.

Bedplate.

The bedplate casting is first marked off in the usual way, as a casting of this size is liable to twist and it must therefore be proved before proceeding to machine it. The top of the bed is first planed within $\frac{1}{16}$-inch of finished size then reversed and the bottom finished off to size. The bed is then reversed again and the top finished off to fine limit gauges. Two location strips are left on the outer side of the bed and these must be accurately positioned in relating to the bearing horns, as all subsequent operations are located from that particular point. After planing, the main bearing stud holes are drilled, tapped, and studded, ready to receive the caps, which are machined separately in all but the bore. After the caps are fitted in position the bed is levelled up on the horizontal boring machine in the same way as it will subsequently be fixed in the erecting shop and latterly on the test bed.

You will notice that the boring bar is supported by two outer bearings, and a support between every two bearings, the supports being located from the strips previously mentioned. The machine merely rotates the bar and all bores are cutting simultaneously in the roughing operation and finished off singly to ensure accuracy. This method is such that the maximum error in mal-alignment is within a tolerance of .002-inch.

The bedplate is now ready for bedding the bearings. A large cast iron mandrill, the same diameter as the outer shells, is dropped into the crankshaft bores and bedded accurately in relation to the planed surfaces. This operation ensures that all bearings will be interchangeable should it be necessary to change any in service. The backs of the bearings are now bedded to the cast iron and then another mandrill which is exactly the running clearance larger than the crankshaft is bedded into the white metal surface and when this can just be rotated with the bearing caps screwed hard down the bed is ready to receive the crankshaft. It should be noted that the crankshaft is not used for bedding at all and that running clearances are a known factor and not something determined by the individual.

The studding operation is carried out by the erectors, and every stud is cleared away at the bottom of the thread so that there is no binding and undue pressure on the casting through wedging. I do not favour putting in important studs in the machine shop owing to the liability of an operator putting studs in damaged tapped holes.

The Crankcase.

Now let us take the housing. This is marked off in the usual way, and the first operation is planing the bottom within $\frac{1}{16}$-inch of finished size. The housing is then reversed and the top side roughed and finished off to size. The liner bores are now machined in a fixture which has piloted bars supported at each end and driven through a universal joint. After the bores are finished two locating plugs are put into the end bores and the planing of the camshaft bearing locations is proceeded with, thus ensuring that the camshaft portion is dead right to the cylinder bore and consequently the crankshaft centre. The housing is then reversed and the bottom flanges finished off to size in relation to the cylinder liner bores. The housing is then drilled ready to offer up to the bed and the stud holes are marked off through the housing flange after checking that the housing is positioned on the bedplates with the centre of the cylinder liner bore exactly between the crankshaft bearings.

Cylinder Liners.

The liners are made from a special hard close grained mixture of cast iron. The first operation is forming the spigot end of the liner with its corrugated grooving. It is then ready for pulling into special faceplates on turret lathes locating always from the spigot. The liners are rough machined inside and out and then left for some time to release machining stresses. The finishing operation is done in exactly the same way and the bore is finished within .003 inch of finished size. The liner is now ready for grinding, and here you see it in position on this large internal grinder simply resting on ball locations by its own weight. The grinding operation is almost a burnishing one, and it is obvious that the turret lathe operations must be dead accurate to permit of such a small grinding allowance being left. The tolerance of the turret operations is within .0015 inch and all bores are ground to dead size. Liners right up to the capacity of this machine for length are done in this No. 20 Herbert turret lathe, and the times possible with proper tool equipment are such as to relegate all other liner boring machines to the realms of the past.

Cylinder Heads.

Cylinder heads are one of the most ticklish machining propositions for the oil engine manufacturer. First of all, the analysis must be so closely watched that it is necessary to take test pieces from every cast. In addition, one head in 50 is broken up to check the coring of the casting. The metal is extremely hard and necessitates the use of Widia to get through the initial hard skin.

The first operation on a cylinder head is done on a Ward No. 17, and the tooling necessary for this job indicates that the machine

is given some stick. A rough cut is taken across the face, and then the choke is machined out to form a support for the very large form tool assembly which rough forms the complete combustion chamber at one operation. A secondary box similarly tooled sizes the head and the head is then reversed ready for finishing on the other side.

The head is now ready for machining the valve pockets, using a specially raised No. 20 turret lathe swinging a large fixture with the cylinder head located from its spigot. The cylinder head can be indexed to the various positions required and the various pockets formed by gauged cutter bars always using a roughing and finishing box to ensure accuracy. Every bar is piloted, and I might mention here the continuous heavy duty to which these turret lathes are exposed is a credit to the manufacturers, and it is my humble opinion that the two well known types of machines illustrated lead the world for this particular type of machine, not only in design, but in endurance.

The turret lathe up to its capacity has displaced many types of boring and turning mills both horizontal and vertical, and the production costs of the items so changed over can show something like a five-fold saving. In the heavy engineering works I am quite sure that when better times come the demand will be for larger and larger turret lathes, and with the advent of better and better high speed steels, their range and scope will be much widened.

Pistons.

Pistons are made of special close grained cast iron, and the first operation is rough machining all over in the ordinary engine lathes. The piston is then heat-treated, after which it is finished on the skirt to grinding size, and the grooves carefully finished to size by single point tool. The piston is now ready for boring the gudgeon pin hole, which operation is carried out on a turret lathe. The skirt is now ground and the piston end touched up with the grinding wheel so that the skirt is dead true to the end. The piston is then dropped on a spigot location on an internal grinder to have the gudgeon bore ground. The piston is then checked for gudgeon alignment by passing a long bar through the bores, and the maximum error allowance is .002 inch in two feet. The grooves are also carefully checked and the diameter of the piston is stamped on the head, and every piston of a diameter is within .0005 inch of dead size.

Connecting Rods.

The connecting rods are drop stampings, and are centred and roughed out on ordinary lathes. The small end and palm end faces are machined on a double shaping machine, always locating from the centres of the rod. It is interesting to note that shaping rods

easily beats milling for finish and accuracy. The rods are all roughed first, then scrape finished to size. This operation must be accurate as one side of the rod and the centre is used thereafter as location points for subsequent operations. The rod is now ready for boring the small end. The final sizing is done by means of a floating reamer. The next operation is the boring of the bolt holes from the same location points. This is done in a similar fixture as a two-spindle horizontal boring machine, and these holes are dead in line with the small end and palm end both ways. The rod is now upended and checked for alignment before the bush is put in. As everybody knows, the bush being pressed in results in distortion of the bore necessitating a further reamering operation to finish to running clearance size. Again, the small end is checked for alignment with the palm end. The rod is finally drilled up the centre for lubrication purposes, and the lower part of the hole also serves as a balancing medium.

Bearings.

There is perhaps no part of an engine more important than the bearings, and there is probably no part that gives the manufacturer more trouble. We all know the difficulty in making white metal adhere to the bearing shells, and many of us are familiar with the mosaic like pattern which a bearing assumes after it has left its anchorage. Like many other problems the solution is a very simple one when you know the way. Let me say that it is no use dealing with the bearing problem in a perfunctory manner. The matter must be approached scientifically, and a special department set aside to concentrate on the many problems which arise. In the bearing shop the gas is generated in an anthracite producer and fed to the furnaces. There are hooded furnaces for melting up scrap returned from the machine shop. The scrap is collected in graded bins and melted up with the additional ingredients required to make up a particular mixture.

Here we have hot plates for heating up the shells and apparatus used in the running up process. There are two tinning baths, one for the primary and the other for the secondary operation. The ordinary melting furnaces maintain the metal at a dull red heat about 600° C. Although I do not consider this temperature at all critical, and I know it is against the text book practice, but the proof of the pudding is the only factor which counts, and I can assure you that the practice I shall outline has the merit of producing bearings which have a white metal lining which cannot be parted from the bearing shell, and on the surface of which there is not the slightest flaw. There is no necessity to provide an anchorage in the shape of dovetailed grooves or holes as these are quite ineffective unless you have perfect adhesion between the shell and the white metal.

The shells are usually of steel and machined to a perfectly smooth finish. The shells are then heated on the hot plate, and are brushed with clay wash where the tinning is not desired. They are then dipped into the primary tinning bath in the usual way and allowed to cool slightly before tinning a second time. It is obvious that as the shell cools the more the tinning mixture will adhere to it. The centrifugal machine, which has been previously fitted up with the particular size of bearing clamps to be used, is now heated up by means of a gas jet. After the running process has started the apparatus retains sufficient heat for efficient working. The head is rotated at a high speed anything up to 1,200 R.P.M. according to the the size of the bearing, and the metal from a ladle of predetermined size is poured down the chute, and that is all there is in it. The machine continues to rotate for a minute or so to allow the bearing to set, after which it is removed and the process repeated. An 85 per cent. tin mixture is used for large and small end bearings, and 69 per cent. tin mixture for main bearings.

In the machining of bearings the main bearing shells are all machined in halves for the sake of interchangeability. The outer diameter if, of course, left oversize until the metal has been run in and it is then completely finished to size. The large end bearings are machined oversize until the finishing operation is reached, and then it is essential to note that the location of the shell is always from the spigot recess. The face which comes next the palm end of the rod is surface ground to the bore, and it is obvious that the rod and bearing can be bolted together and be in perfect alignment without any handwork whatsoever beyond the bedding of the running size mandrills. No bearings are bedded to the actual crankshafts at all, as these bedding mandrills give the bearing the exact running clearance necessary, the individual errors of workmen are avoided.

Crankshaft.

The crankshaft is a 35 ton tensile steel forging, and it is necessary to heat-treat after the forging stage. Test pieces are taken from the web and these are prepared and pulled in the laboratory before any further operations are proceeded with.

The first operation is roughing out the webs on the puncher slotting machine. The crank is then centred and rough turned in a lathe on the main bearings to within $\frac{1}{4}$-inch of finished size. It is then taken to the surface table and the crank dogs and eccentric stays are fixed in position in correct alignment. It is now taken back to the lathe where the crankpins are machined to within $\frac{1}{4}$-inch of finished size so that the whole crank is now within $\frac{1}{4}$-inch of finished size, and the various machining stresses having been released.

The flats and crowns of the webs are now machined on a large Butler double headed shaper, after which the crankshaft is finish-

turned to size by repeating several of the previous lathe operations. The pins are finally finished off by lead lapping and are within .001-inch for roundness and within .0015-inch per foot for alignment in any direction. Finally, the crankshaft is drilled for the oilways and on the flange for the flywheel bolt holes. The crank is now ready for inspection and this is done in the following manner.

Each main bearing of the crankshaft is supported in adjustable V blocks by means of which the crank is brought into correct alignment. On each main bearing a clock indicator is placed, and between each web a breathing clock indicator is fixed, the crank is then rotated and readings taken at four intervals, viz., No. 1 pin in bottom position, then front, top, and back, finally indicator clock readings are checked in first position to rectify any error that may have arisen. The roundness of main bearings and breathing in crank having been checked, each crankpin is clocked in bottom position by an indicator to give vertical alignment, and the horizontal alignment is taken with crankpin in front position. Length of throw is obtained with crankpin in bottom position, this being the difference between journal and crankpin centres as measured from the table by a height gauge. The error of angles of crankpins are checked by means of a dividing head and indicator.

Camshaft.

The camshaft is a most important item and is a plain steel shaft with casehardened cams keyed on in the correct relative position for each cylinder. It is this difficulty of arriving at the exact position of the keyways that necessitates a special fixture. The keywaying machine is a special one made by Holroyd, and has a very stout spindle. It is capable of milling a keyway $2\frac{1}{2}$-inches wide by $\frac{3}{4}$-inch deep at one cut. The dividing arrangement fixed on the end of the shaft gives the exact position of each keyway and the correct sequence. As the cams are all machined from a broached keyway, the only uncertain factor is the fitting of keys.

Fuel Pumps.

The manufacture of fuel pumps and atomisers is one of the most difficult manufacturing problems any firm could be up against. The pump is a steel body fitted with plungers and guides and spill valves to correspond with the number of cylinders. There are also various cages carrying suction and delivery valves, and the manufacture of these components involves the finest precision grinding and lapping operations, as well as really high class turret work, and this is only arrived at by long practice on the part of the operators. The atomiser is much the same from the point of view of skill required in its manufacture, and each part must not only be minutely inspected for size, but subjected to most stringent pressure tests.

On the efficiency of the pump and atomisers the whole successful running of the engine depends.

Erection.

Now we might look at the erection of the engine after the various assemblies have been prepared by the fitting department. The bed is first levelled up on girders and the crankshaft bedded in as previously described. The crankshaft, of course, has had its oil passages carefully cleaned and is put into position, and the bearing caps tightened down. The crankcase housing has the removable liners put into place and is subjected to a water test of 50 lbs. per square inch. Great care, of course, has to be taken in putting liners into place, as they are very easily distorted and put out of alignment.

The complete housing is now lifted into position, and the alignment of the bores is checked by means of a dummy piston and rod, and as great care has been exercised in the previous machining operations, it is very rarely necessary to make any adjustment. It should be noted that the large end bearings have been previously clamped to their particular pins. The pistons complete with rings and rods are now dropped into place, and bolted up to the large ends. When I tell you that the small end running clearance is .0025 inch, and the large end .005 inch, you will realise that there is no room for the slightest mal-alignment. The cylinder heads, having been fitted up with their inlet and exhaust valve cages and other valve gear, are now put into position, lined up, and pulled down tight. The camshaft assembly is next dropped into position and the various push rods sprung into place. The pump and governor assembly is next placed in position, and the gears properly meshed so that the valve operating cams and fuel pump cams are all correctly timed in relation to the various crankpin positions. Valve clearances are then set by means of a clock gauge, and the whole cycle of operations is carefully checked over by an inspector. The lubrication system is then piped up and after the outside details have been fixed the covers are finally closed up and the engine is ready for the test pits.

Testing.

The engine is lifted complete wherever possible, and placed on the running girders, and again levelled up to a Heenan & Froude brake. The various piping for the water, fuel, air, and exhaust arrangement is connected up, and the engine is thoroughly primed through with lubricating oil by means of a hand pump. The engine is then turned round by compressed air for a few minutes, and the fuel pump is let in gradually and "off she goes." After about six hours of running, during which all necessary adjustments are made to balance up the running of each cylinder, the engine is gradually

brought up to full load and is then ready for her official test, which may vary from a week's non-stop running to four hours full load, with two hours overload to the extent of 10 per cent. and half an hour at 25 per cent. overload.

The fuel consumption must be to guaranteed figures before the engine is passed off test. The engine is then dismantled after test and the various important parts such as bearings, valves, cams, pistons and rings, etc., are examined, after which the engine is re-assembled and given a final short run before being passed off to the paint and packing shops for despatch.

Outside Erection.

With engines of this size involving, very often, complete power house installations, it is essential to have a first-class staff of outside erectors. It is obviously useless to exercise every care and attention to details in the shops if the same care and attention is not applied to the outside erection on site.

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